

POLARIMETRIC DECOMPOSITION ANALYSIS OF THE DEEPWATER HORIZON OIL SLICK USING L-BAND UAVSAR DATA

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ABSTRACT

We report here an analysis of the polarization-dependence of L-band radar backscatter from the main slick of the Deepwater Horizon oil spill, with specific attention to the utility of polarimetric decomposition analysis for discrimination of oil from clean water and identification of variations in the oil characteristics. For this study we used data collected with the UAVSAR instrument from opposing look directions directly over the main oil slick. We find that both the Cloude-Pottier and Shannon entropy polarimetric decomposition methods offer promise for oil discrimination, with the Shannon entropy method yielding the same information as contained in the Cloude-Pottier entropy and averaged intensity parameters, but with significantly less computational complexity.

1. INTRODUCTION

On June 22-23, 2010, NASA deployed the airborne UAVSAR platform to the Gulf of Mexico to study the polarimetric radar properties of the Deepwater Horizon oil spill, gather data for improved discrimination and characterization of oil slicks, and evaluate the environmental impact of oil in coastal ecological areas by tracking oil incursion into wetlands and monitoring the impact and recovery of marshland vegetation. We have analyzed the UAVSAR data collected over the main oil slick near the Deepwater Horizon rig site to address the first two of these science goals. Our analysis is used specifically to demonstrate the applicability of the fully-polarimetric L-band UAVSAR radar to oil spill detection and more generally to determine the scattering properties of polarimetric L-band radar from oil. The broad extent of the Deepwater Horizon oil slick has allowed characterization of radar backscatter for a very large range

of incidence angles, from $27^\circ - 64^\circ$. The low noise floor of the UAVSAR radar allowed detection of radar returns in both co-polarized (HH and VV) and cross-polarized (HV) channels across most of the swath, permitting a full characterization of the scattering mechanism through polarimetric decomposition analysis. Previous studies of oil slicks have been limited in their ability to measure the cross-polarized channel returns, either because the instrument did not have quad-pol capability or because the cross-polarization returns were below the instrument noise floor. Using the two UAVSAR data sets obtained directly over the main oil slick, we analyzed and compared the radar backscatter for all of the polarization channels (HH, VV, and HV) and decomposed the data using Cloude-Pottier $H/A/\bar{\alpha}$ eigenvector decomposition [1] [2] and the Shannon entropy decomposition [3] for several areas of known oil contamination in the vicinity of the Deepwater Horizon site and for areas of clean water. The usefulness of the different polarization-dependent parameters for discriminating oil from water and for identifying variations within the oil of the slick was evaluated in order to determine the best parameters upon which to base an oil slick identification and classification algorithm.

2. UAVSAR GULF OIL SPILL CAMPAIGN

During the Gulf oil spill deployment, the UAVSAR radar was used to image the Gulf of Mexico area both in the open water and over land along the coast. In the two day deployment, fully polarimetric radar data was collected along 5500 km of flight lines, covering an area of more than 120,000 km². The UAVSAR flights occurred after a significant volume of oil had been released into the Gulf of Mexico since the spill inception on April 20, 2010.

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The UAVSAR platform is a Gulfstream-3 aircraft instrumented with a L-band polarimetric synthetic aperture radar that operates with 80 MHz bandwidth from 1.2175-1.2975 GHz [4]. The radar was operated with both H-polarization and V-polarization in transmit and receive (quad-polarization) modes. UAVSAR images a 22 km wide ground swath at 22°- 65° incidence angle with 1.7 -m slant range resolution in the across-track direction and 1-m ground resolution in the along-track direction. The combination of the UASAR radar's full polarization capability with an extremely low noise floor makes it an excellent instrument for polarimetric SAR studies. The noise equivalent σ_0 of the system is -53 dB at its minimum near the mid-range of the swath and decreases to -40 dB in the near and far range limits.

We have analyzed the data from two UAVSAR flight lines acquired on June 23, 2010, over the Gulf of Mexico near the Deepwater Horizon rig site to study the relative changes in intensity and polarimetry-dependent parameters between clear water and the oil slick. The two lines used in this study are gulfco_14010_10054_100_100623 (collection time 23-June-2010 20:42 UTC), which passed directly over the Deepwater Horizon rig site at a heading of 140°, and gulfco_32010_10054_101_100623 (collection time 23-June-2010 21:08 UTC), which passed immediately to the west of and parallel to the first line along a 320° heading. The multi-look complex data for the HH, HV, and VV normalized radar cross section were used for this analysis with three range (cross track) and twelve azimuth (along track) looks.

3. SAR IMAGING OF OIL ON WATER AND POLARIMETRIC DECOMPOSITION

Previous studies of oil slicks have either used surface brightness alone or surface brightness plus polarization properties to distinguish oil from false returns, with polarimetry providing additional information for identifying and classifying oil spills (see, for example, [5] [6] [7]). Over the ocean, SAR detects variations in surface roughness that arise from varying wind speeds, wave-wave and wave-current interactions, and the presence of surface films.

Marine slicks are composed of two major types of hydrocarbons, mineral oil including petroleum-based material and biogenic films, also known as surfactants, from biological processes. Both mineral and biogenic

slicks typically form thin microlayers on the ocean surface, on the order of 10^{-6} m and 10^{-7} m thick, respectively, which are effectively dispersed by waves, wind, and currents. Both forms of slicks have low relative dielectric constants, with real components between 2.2 and 2.3 and imaginary components less than 0.02, over the frequency range of 0.1 to 10 GHz. The relatively low dielectric constant causes the intensity of the backscatter over oil to be consistently less than that of adjacent water, regardless of surface conditions. While mainly thin films have been studied in past oil spills, the Deepwater Horizon spill was unique in the quantity of oil released (4.9 million barrels over 3 months), so both sheen and thicker oil layers and more complex oil-water emulsions were present compared to oil slicks studied previously.

Oil on the sea surface effectively smooths the ocean surface and reduces the radar backscatter compared to the surrounding ocean. The viscoelastic properties of the marine slick material effectively dampen the capillary and small gravity waves by both suppression of wave growth and an increase in wave dissipation, through an increase in surface tension and a reduction in wind friction. Thus the smoothed slick-covered areas appear darker than the usually wind-roughened surrounding ocean in radar images.

Information about scattering processes can be gathered from polarimetric SAR (POL-SAR) data by analyzing the individual components of the scattering matrix or by using various decomposition methods. Most decomposition methods attempt to relate the polarimetric backscatter to the physical properties of the scatterers, for example, surface, volumetric, and dihedral scattering. The search for an oil slick in a large body of water presents a unique challenge to these decomposition methods due to the fact that all of the interesting backscatter is reflected from a surface whose apparent roughness varies as a function of time, location, and physical characteristics, such as viscosity. However, because the apparent roughness of the surface of an oil slick will be different from that of clean water imaged at the same time and in the same area, the relative contributions of the different polarimetric channels are expected to change. This change in polarimetry will manifest in the elements of some decomposition methods.

One such decomposition method is the Cloude-Pottier $H/A/\bar{\alpha}$ eigenvector decomposition method [1], which utilizes complimentary elements calculated from the eigenvalues and eigenvectors of the averaged 3×3 co-

herency matrix. Averaging the coherency matrix over a defined space allows us to stochastically evaluate the properties of distributed scatterers rather than single point scatterers. Together the decomposed elements of the averaged coherency matrix show whether there exists a dominant scatterer and defines the mechanism of the most dominant scatterer(s)—surface, volumetric or dihedral.

We have used both the $H/A/\bar{\alpha}$ decomposition, augmented by the averaged intensity Λ [2], and the Shannon entropy decomposition [3] to investigate the sensitivity of different parameters to oil detection and characterization. The Shannon entropy decomposition has not previously been applied to oil slicks, but it is computationally simpler than the $H/A/\bar{\alpha}$ decomposition and might be better suited to operational real-time oil detection systems used in emergency response operations.

4. RESULTS AND DISCUSSION

We have found potential value in both the Cloude-Pottier decomposition and the Shannon decomposition for oil detection and characterization. The sensitivity of the $H/A/\bar{\alpha}/\Lambda$ parameters to the oil is clear in the averaged intensity, which is shown in Figure 1 for the two flight lines. The oil slick shows up consistently with a much lower signal level than the clean water. The variations within the slick are also clearly shown in the parameter. Our study indicates that the anisotropy and the averaged intensity from the $H/A/\bar{\alpha}$ decomposition both are sensitive to oil and hold promise for oil characterization. This is a new result for the anisotropy because previous studies generally have not had a low enough instrument noise floor to be sensitive to the cross-polarized backscatter amplitude. Our results and method are reported in more detail in [8]. The intensity and polarimetric components of the Shannon entropy yield the same information as the eigenvalue-based averaged intensity and entropy, but require calculating only the trace and determinant of the coherency matrix. For the UAVSAR data, the total Shannon entropy distinguishes oil from water at all incidence angles for which the backscatter return is above the instrument noise floor.

5. ACKNOWLEDGMENT

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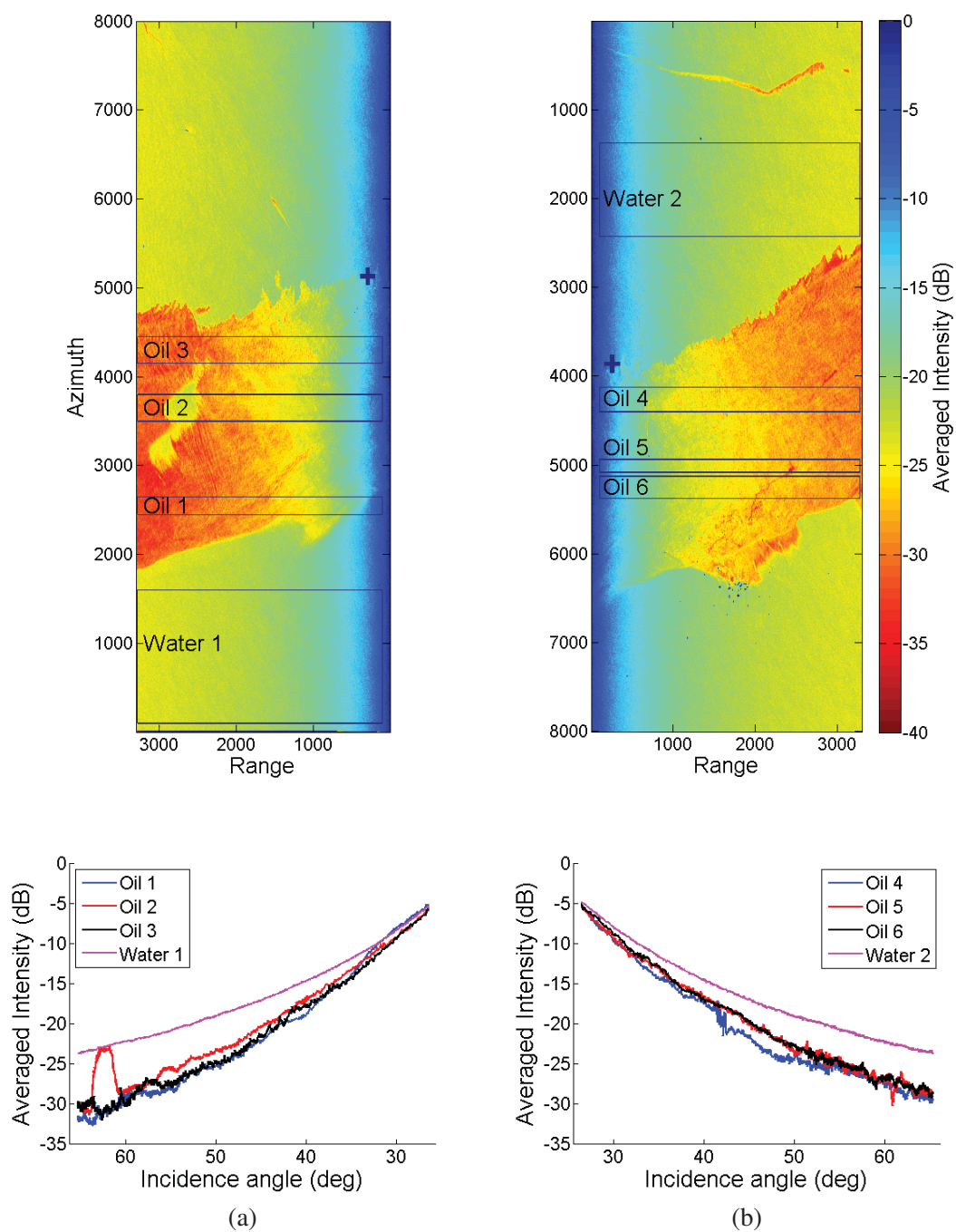


Fig. 1. Averaged Intensity (Λ) images and corresponding cross-track profiles for (a) track 32010 and (b) track 14010. The range and azimuth axes in the images are in pixel units, with pixel size 7.2 m in azimuth and 5.0 m in slant range. The crosses locate a common point in the two overlapping images. The average value as a function of incidence angle in the outlined areas of clear water and oil are plotted below the images.